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CHAPTER 9

STANDARDS AND SPECIFICATIONS

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1. INTRODUCTION

Standards and specifications for power and control cables have been prepared in the United States by various industry organizations since the early part of the twentieth century. Electrical cables are manufactured to these requirements depending on the application of the particular installation.

The power cables that are covered by these standards and specifications can be classified under three major categories:

- | | | |
|--------------------------|-----------------------|-------------------------------------|
| ☐ | Low Voltage Cables | Rated up to 2,000 volts |
| ☐ | Medium Voltage Cables | Rated 2,001 through 46,000 volts |
| ☐ | High Voltage Cables | Rated 69,000 volts to 500,000 volts |

The most widely used documents in the North America are those issued by the Insulated Cable Engineers Association (ICEA) in conjunction with the National Electrical Manufacturers Association (NEMA), the Association of Edison Illuminating Companies (AEIC), the Rural Electrification Administration (RUS), and Underwriter's Laboratories (UL).

2. MANUFACTURERS (ICEA / NEMA)

2.1 ICEA

This group was formerly known as IPCEA. They removed the "Power" from their name to more accurately describe a broader scope of activities. Sections in ICEA include:

- | | |
|-----------------------------|-----|
| Extruded Dielectric Power | EDP |
| Portable, Communication | COM |
| Control and Instrumentation | C&I |

Membership is made up of technical employees of cable manufacturers in North America. They develop standards, guides, and committee reports on all aspects of insulated cable design, materials, and applications. They work with other

organizations toward the development of joint standards. Many of their standards are subject to the approval of NEMA and these are published as a joint ICEA / NEMA standard.

These standards encompass the entire cable: conductor, shields, insulation, jackets, testing, etc. The only possible omission is packaging. This is considered to be an area that is not allowed by United States' law.

2.2 NEMA

NEMA's members are from cable manufacturing organizations and generally they are from the commercial side of those companies.

3. ASTM

The American Society of Testing and Materials prepare and publish standards for many of the materials in wire and cable. A notable example is for conductors. ICEA references these documents in their Standards, so the details of conductors are covered by ASTM.

4. AEIC

Cable specifications have been written by the Cable Engineering Section of the Association of Edison Illuminating Companies, a group of investor owned and municipal utility company engineers, since 1920. They also prepare Guides that pertain to power cables.

Their first specifications were written for paper insulated cables for medium voltage applications. Presently their specifications cover all forms of laminated cables from 5 to 345 kV such as paper-insulated, lead-covered, low-pressure oil-filled, and pipe-type. These specifications include conductors, insulations, sheaths, shields, jackets, and testing requirements.

AEIC also prepares specifications for extruded dielectric cables from 5 to 138 kV that build upon the ICEA documents (hence also on the applicable ASTM requirements). AEIC hence uses the ICEA standards for such items as conductors, shields, jackets, and testing requirements. A unique feature of AEIC's extruded cable specifications is that they require a qualification test be performed on a sample of cable that represents the cable to be manufactured.

Another feature of AEIC's specifications for extruded cables is a checklist of the available options is presented. This can be useful for those users that are in the process of developing a user specification for themselves.

5. RURAL ELECTRIFICATION ADMINISTRATION (now RUS)

This is also a user group of the U.S. Department of Agriculture that develops standards for the Rural Electric Cooperatives of the United States.

6. UNDERWRITER'S LABORATORIES (UL)

Underwriter's Laboratories has published several standards for low voltage cables and one for medium voltage cables.

7. FEATURES OF STANDARDS AND SPECIFICATIONS

7.1 Conductors

7.1.1 Resistance. Both copper and aluminum conductors are covered by ASTM and ICEA standards. Since resistance is the governing factor for establishing conductor size in most instances, they both establish a maximum resistance for each AWG and kcmil size. Conductor diameters and individual strand diameters are no longer required to meet a minimum dimension.

One of the possibilities with aluminum is that the conductivity may be better than the required 61.2%. The result can be that aluminum with 62% conductivity does not have the cross-sectional area of say a 1,000 kcmil conductor. This can be an important difference for such large conductors when they are connected using crimp connectors. Attention to the design of the connector and the compression tool and dies will keep this slight reduction in metal area from being a problem even during emergency overload conditions.

7.1.2 Compressed Strand. ASTM standards for stranded conductors give the manufacturer the option of "compressing" Class B and C conductors. This means that they can decrease the overall diameter of the conductor by a maximum of 3% from that of a concentric conductor. The need and advantages for such compression was presented in Chapter 3. Another way of saying this is that even if "concentric" stranding is requested, the manufacturer has the option of providing "compressed" strand.

7.1.3 Temper. An important decision that must be made involves the temper of the metal. This option should be based on such factors as the pulling forces, flexibility, and also on the cost.

The harder the temper, the greater force can be applied to the conductor during installation. A half-hard aluminum conductor will withstand less force than a 3/4 or full hard conductor. On the other hand, that increase in temper produces a conductor that requires more force to bend – it is less flexible. This additional

force may be negligible when compared with the bending forces of the finished cable, however. When conductors are drawn during the manufacturing process, the metal is work hardened and the temper increases. Annealing during the drawing process or after the conductor is formed will decrease the temper, but this takes energy so there is an increase in the cost of an annealed conductor. All of these points need to be weighed before a decision is reached.

7.1.4 Identification. Cable manufacturers have the capability of indent printing on the center strand of a seven strand, or greater, Class B or C conductor. If requested at the time of the inquiry, they can print the year of manufacture and their name at one-foot intervals on this center strand. This provides a lasting identification of the manufacturer and the year.

7.1.5 Blocked Strand. Another consideration is to block, or fill, the strands of a Class B conductor with a compound that eliminates almost all the air from the interstices. This prevents the accumulation of moisture in the air space as well as prevents any moisture from longitudinal movement along the cable. The elimination of water in the strand reduces the treeing concerns and increases the life of cables in accelerated treeing tests. ICEA Standards contain a test for the effectiveness of this "water blocking" [9-1].

Another method of keeping water from entering (or leaving) the strand is to install a metal barrier in the semiconducting strand shielding. The layer is a "sandwich" of the semiconducting material with a lead or aluminum overlapped tape in the center.

7.2 Conductor Shielding

Conductor shielding (either a semiconducting or a stress control layer) is required for cables rated 2,000 volts and higher by these standards. Conductor shielding normally consists of a semiconducting layer applied between the conductor and the insulation. For this layer to function properly, it should be inseparably bonded to the insulation to ensure there are no air voids between the conducting layer and the insulation.

For compatibility reasons, this extruded semiconducting material is usually made from the same polymer as the insulation that it will be adjacent to ensure compatibility of the two materials. Its conducting properties are obtained by adding particles of special carbon black. The present requirement for the maximum resistivity of this layer is 1,000 meter-ohms. Industry standards require this material to pass a long-time stability test for resistivity at rated emergency overload temperature of the cable. Accelerated tests have shown that the cleanliness of the material can significantly effect the life of the cable when it is in a wet environment. A "super clean" semiconducting material can

improve the life of a cable in an accelerated water treeing test by three to five times.

The stress control layer that may be used rather than semiconducting has properties that are best describe it as having a high dielectric constant (high K) material. This means that it acts like a rather poor conductor and produces a very low voltage drop between the conductor and the insulation. It does provide the stress control that is needed for smoothing out the conductor surface.

It is permissible to apply a conducting tape over the conductor and under the semiconducting layer. This functions as a binder and is sometimes used for larger conductors.

If a semiconducting conductor stress control layer is used, the resistivity shall be measured using the following procedure. A sample approximately 6 to 8 inches long shall be taken and the metallic shielding removed. The sample shall be cut in half by making two longitudinal cuts 180° apart. The conductor shall be removed. One of the 180° sections shall be painted with silver electrodes placed at least two inches apart on the conductor stress control layer to act as potential electrodes. If greater accuracy is desired, current electrodes may be placed one inch beyond each potential electrode.

The resistance shall be measured between the two potential electrodes. The power of the test circuit shall not exceed 100 milliwatts.

The volume resistivity shall be calculated from the following equation:

$$P = \frac{R (D^2 - d^2)}{100 L} \quad (9.1)$$

where P = Volume resistivity in ohm-meters
 R = Measured resistance in ohms
 D = Diameter over conductor stress control layer in inches
 d = Diameter over conductor in inches
 L = Distance between electrodes in inches

7.3 Insulations

Crosslinked polyethylene (including tree retardant XLPE) and ethylene propylene rubber are the dominant materials presently being used as the insulation for medium voltage cables.

7.3.1 Crosslinked Polyethylene. AEIC has a specification for 5 to 46 kV medium voltage cable [9-5] that covers crosslinked (thermosetting) polyethylene cables. At this time, there is not any medium voltage thermoplastic polyethylene power cable being manufactured in North America.

AEIC CS5 and ICEA S-94-649 require that numerous tests be performed on the material that will be used in the manufacturing process. Applicable tests and their requirements include:

Physical Requirements -- Unaged

Tensile strength, psi, minimum, room temperature	1,800
Elongation, percent, minimum, room temperature	250

Physical and Electrical Requirements -- Aged

After Air Oven Test for 168 hours at 121 °C	
Tensile strength, % of unaged, minimum	75
Elongation, % of unaged, minimum	75

Electrical Characteristics at Room Temperature	
SIC at 80 V/mil, maximum	3.5
Dissipation Factor at 80 V/mil, maximum, XLPE	0.1
Dissipation Factor for filled or TR-XLPE	0.5
Insulation Resistance Constant	20,000

7.3.2 Ethylene Propylene Rubber. ICEA S-94-649 requires that tests be performed on the material to be used for these cables and that they have the following values:

Physical Requirements -- Unaged

Tensile strength, psi, minimum at room temperature,	EPR 1	700
	EPR 2	1,200
	EPR 3	700
Elongation, percent, minimum at room temperature, all three		250

Physical and Electrical Requirements -- Aged

After Air Oven Test for 168 hours at 121 °C		
Tensile Strength, percent of unaged, minimum,	EPR 1	75
	EPR 2	80
	EPR 3	75

Elongation, percent of unaged, minimum, EPR 1	75
EPR 2	80
EPR 3	75

Electrical Characteristics at Room Temperature

SIC at 80 V/mil, maximum, all three	4.0
Dissipation Factor at 80 V/mil, maximum, all three	1.5
Insulation Resistance Constant (K), minimum, all	20,000

7.3.3 Insulation Thickness And Test Voltages. Both crosslinked polyethylene and ethylene propylene rubber insulated cables have the same wall thickness requirements and test voltages in accordance with ICEA standards. The ac test voltage in ICEA is approximately 150 volts per mil of specified wall thickness.

AEIC specifies wall thickness for cables with both of these insulations for 5 to 46 kV service. Two important differences in the two philosophies is that AEIC no longer requires a dc test for these cables. The other is that they provide two wall thickness for each voltage rating -- Column A and B. See note 2 of Table 11-2 where they discuss the factors to be considered in making the choice.

RUS specifications require the use of Column B wall thickness for cables that are manufactured to their needs unless dispensation is given on the basis of selective designs.

7.4 Extruded Insulation Shields

In addition to the conductor stress control layer, medium voltage, shielded power cables require an insulation shield. The insulation shield consists of a nonmetallic covering directly over the insulation and a nonmagnetic metal component directly over or imbedded in the nonmetallic conducting covering. Since the nonmetallic insulation is over the insulation, the stresses are lower than at the conductor interface. This outer layer is not required to be bonded to the insulation for cables rated up to 35 kV. At higher ratings, bonding is both required and recommended. The insulation and the semiconducting material must be compatible since they are in intimate contact with one another.

7.4.1 Strip Tension. AEIC has established peel strength limits for the removal of the semiconducting layer for 5 to 35 kV cables. The lower limit is for cable performance and the upper limit is set to permit removal without damaging the surface of the insulation.

The AEIC test calls for a 1/2 inch wide strip be cut parallel to the center conductor. This cut may be completely through the layer (in contrast to field

stripping practices). The 1/2 inch strip is removed by pulling at a 90° angle to the insulation surface at a set rate of speed. The limits are:

Table 9-1
AEIC Strip Tension Limits

Material	Lower Limit in Pounds	Upper Limit in Pounds
XLPE and TR-XLPE*	6	24
EPR	4	24

Note *: Recognition has been given to the availability of insulation shield with lower stripping tensions, but they are not covered by the 1994 version of AEIC CS5.

7.4.2 Resistivity. The volume resistivity of this extruded layer shall not be greater than 500 meter-ohms when tested in accordance with ICEA procedures. This layer can be used only as an auxiliary shield and requires a metal shield in contact with it to drain off charging currents and to provide electrostatic shielding.

The volume resistivity level is half that of the conductor shield because this layer is subject to chemical action from the environment. The function of the shielding properties would be acceptable with a higher value, but concerns over long-time stability have influenced this level.

The resistivity of the extruded layer shall be measured using the following procedure.

A sample approximately 6 to 8 inches long shall be taken and the outer coverings including the metallic shield shall be removed. Four silver-painted annular-ring electrodes shall be applied to the outer surface of the insulation shield. The inner two electrodes will be for the potential application and shall be at least two inches apart. If a high degree of accuracy is required, a pair of current electrodes shall be placed at least one inch beyond each potential electrode.

The resistance shall be measured between the two potential electrodes. The power of the test circuit shall not exceed 100 milliwatts.

The volume resistivity shall be calculated as follows:

$$P = \frac{2 \times R (D^2 - d^2)}{100 L} \quad (9.2)$$

where

- P = Volume resistivity in ohm-meters
- R = Measured resistance in ohms
- D = Diameter over insulation shield in inches
- d = Diameter under insulation shield in inches
- L = Distance between potential electrodes in inches

7.4.3 Insulation Shield Thickness. AEIC has established a thickness for the extruded layer of insulation shield to provide guidance for the manufacturers of molded splices and terminations. In May of 1990, they issued an addendum that allowed for thinner layers for cables having an overall jacket or sheath.

7.5 Metallic Insulation Shields

In addition to the extruded insulation shield previously described, shielded cables must have a metallic member over and in contact with the nonmetallic layer. The following options are available for the metallic member.

- Helically wrapped flat metal tape (usually copper)
- Longitudinally corrugated metal tape (usually copper)
- Wire shield (multiple #24 AWG or larger copper wires)
- Concentric neutral wires (#14 AWG or larger to meet conductivity)
- Flat straps (flat metal tapes applied with close coverage to meet conductivity)
- Tape plus wires
- Continuous welded corrugated metal sheath (copper, aluminum, etc.)

Wire shields and flat tapes are the most popular metallic shields and are almost always copper. A 5 mil copper tape with a minimum 10% overlap is generally used when tapes are specified. For wire shields, #24 to #18 AWG wires are used in proper multiples to provide 5,000 circular mils of area per inch of cable core conductivity. The first three types listed above, function as electrostatic shields only since they do not have a limited fault current capacity.

Concentric neutral wires and flat straps are normally specified on URD and UD cables where the metal functions both as a shield and a neutral. These constructions normally use copper wires with an overall jacket applied over the wires for corrosion protection.

In higher voltage cables such as 35 kV to 138 kV, fault currents often may be greater than the capabilities of wires. In those situations, the tape plus wire construction is frequently used.

Where shields must be sized for specific fault current requirements, there are several sources of data such as:

ICEA T-45-482, "Short Circuit Performance of Metallic Shielding and Sheaths of Insulated Cable."

EPRI RP 1286-2, (EL-5478), "Optimization of the Design of Metallic Shield / Concentric Neutral Conductors of Extruded Dielectric Cables Under Fault Conditions."

7.5.1 Concentric Neutral Cables. ICEA standards cover the number and size of concentric neutrals for this type of cable. The concentric neutral conductor shall be uncoated copper wire in accordance with ASTM B3 or tin coated wire in accordance with ASTM B33. The wires of the concentric neutral shall be applied directly over the insulation shield with a lay of not less than six or more than ten times the diameter over the concentric wires.

Although AEIC does not provide information on concentric neutrals, it is important to understand that a full or one-third neutral is not mandated by any standard. Many utilities use smaller amounts of neutral wires based on the fact that too much metal leads to increased losses. RUS standards do not require even a full neutral for URD cables.

7.6 Cable Jackets

Jackets are required over certain types of shields for mechanical protection and during the installation and operation. These shields are the flat tapes, corrugated tapes, wire shields having smaller wires than #14 AWG, and embedded corrugated wires.

There are many possible jacketing materials such as:

- Polyethylene
- Polyvinyl chloride (PVC)
- Polychloroprene (Neoprene, Trade Mark)
- Chlorosulphanated polyethylene
- Chlorinated polyethylene

Their attributes are discussed in Chapter 8.

ICEA standards cover the thickness of these jackets. See Chapter 21 for tables.

8. REFERENCES

- [9-1] ICEA S-19-81 (NEMA WC-3), "Rubber Insulated Wire and Cable, 0 to 28 kV".
- [9-2] ICEA S-61-402 (NEMA WC-5), "Thermoplastic Insulated Wire and Cable, 0 to 35 kV."
- [9-3] ICEA S-66-516 (NEMA WC-8), "Ethylene Propylene Rubber Wire and Cable, 0 to 35 kV."
- [9-4] ICEA S-66-524 (NEMA WC-7), "Crosslinked Polyethylene Wire and Cable, 0 to 35 kV."

These ICEA-NEMA documents are available from:

National Electrical Manufacturers Association
1300 North 17 Street, Suite 1847
Rosslyn, VA 22209

- [9-5] AEIC CS5-94, "Specifications for Crosslinked Polyethylene Insulated, Shielded Power Cables Rated 5 through 46 kV, 10th Edition."
- [9-6] AEIC CS6-87, "Specifications for Ethylene Propylene Rubber Insulated, Shielded Power Cables Rated 5 through 69 kV, 5th Edition."
- [9-7] AEIC CS7-93, "Specifications for Crosslinked Polyethylene Insulated, Shielded Power Cables Rated 69 through 138 kV, 3rd Edition."

These AEIC documents are available from:

Association of Edison Illuminating Companies
600 North 18 Street
P. O. Box 2641
Birmingham, AL 35291-0992

- [9-8] UL Standard 1072, "MV Cables Rated 2,001 to 35,000 Volts."
- [9-9] ICEA T-24-380, "Guide for Partial Discharge Test Procedures."
- [9-10] ICEA P-45-482, "Short Circuit Performance of Metallic Shielding and Sheaths of Insulated Cable," 1979.
- [9-11] ICEA T-25-425, "Guide for Establishing Stability of Volume Resistivity for Conductivity of Polymeric Compounds of Power Cables," 1981.

- [9-12] ICEA T-28-562, "Test Method for Measurement of Hot Creep of Polymeric Insulations," 1983.
- [9-13] ICEA T-22-294, "Test Method for Extended-Time Testing of Wire and Cable Insulations for Service in Wet Locations," revised 1983.

These ICEA documents are available from:

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